CONFIDENTIAL

[redacted] 25X1

November 2, 1959

Dear Sir:

This summary letter report describes the research performed under Work Order No. X, Task Order No. CC, during the period March 27 through July 26, 1959.

The objective of the Work Order No. X research program was to develop a working model of an instrument or system which would measure and then indicate the torques exerted by the moving component of your operating representatives' special two-component tool [redacted] 25X1
[redacted] of interest. Implied in this objective were requirements that any modifications made to the special tool in order to achieve the stated objective should not seriously interfere with the "feel" of the tool during use; and that the accessory instrument, as a whole, should be small, lightweight, self-contained, and reliable. 25X1

More specifically, on the basis of the data obtained under Work Order No. III, Task Order No. CC, and described in the corresponding summary letter report, dated April 2, 1959, it was hoped that an instrument could be developed to cover a range of torques from about 0.2 in.-lb. to 10 to 15 in.-lb. Also, as a means to the objective, the use of electric-resistance strain gages had been suggested as probably being quite meritorious; the additional consideration given to the problem under Work Order No. X showed this suggestion to be well founded.

In connection with a proposed torque meter (system) based on electric-resistance strain gages, the design had basically two aspects, mechanical and electrical. Strain gages, when energized electrically, give an electrical signal when the parts to which they are attached are deformed (strained) by a force or a torque. The problem then was to design a device in which a member would be twisted or bent when the torques to be measured were applied to the tool. This implied, of course, that the handle of the tool would rotate more than the working end of the tool in the course of operation.

The principal design considerations involved in this particular application were as follows: (1) enough mechanical strain should be obtained at the lowest torque so as to give a sufficiently large electrical indication; (2) the mechanical strain should not exceed the yield point of the material used in the strained parts of the tool, at the maximum torque; (3) the relative elastic rotation of the tool should not be so great that it seriously affected the "feel"; and (4) the frictional torque in the tool should be small as compared to the smallest torque to be measured.

In the course of evolving a specific configuration on which to mount strain gages, calculations were made first for a tubular member. It was found that, in order to achieve enough strain in a thin-walled tube so as to obtain a reading of 0.2 in.-lb., the wall thickness would have had to be prohibitively thin for any reasonable tube diameter. Therefore, this approach was discarded, and the design was based on a cantilever beam. Actually, two identical beams were used, mainly to obtain the advantages of a complete four-arm strain-gage bridge within the tool; these advantages were temperature compensation, and more reliable performance resulting from the fact that the gages could be solder-connected within the handle of the tool.

The basic equations governing the design of the torque meter are as follows:

The current through the detecting meter, i, caused by a strain, e, in the strain gages is, for a bridge of four active arms:

$$i = \frac{IGe}{\left(1 + \frac{R_g}{R}\right)}, \tag{1}$$

where:

I = the current supplied to the bridge circuit

G = the "gage factor" of the strain gages = $\frac{\text{relative change in resistance}}{\text{strain}}$

R = the electrical resistance of each gage

R_g = the electrical resistance of the detector.

The strain, e, on the surface of a cantilever beam at points near the mount is:

$$e = \frac{3T}{2Ebx^2}, \tag{2}$$

where:

T = the torque causing bending

E = Young's Modulus of the beam material

b = the width of the beam

x = the half thickness of the beam.

From a review, first, of the characteristics of zero-center microammeters which were available, it became apparent that strain gages should be chosen to give as much output signal as possible. Therefore, Baldwin-Lima-Hamilton Type C-8 gages were selected, because of their high gage factor of about 2.8 and their high resistance of 500 ohms (giving a smaller value of R_g/R in Equation 1). On the basis of using the specific characteristics of these gages and of a typical meter in Equation 1, the minimum usable value of strain was estimated. From this estimated value of strain and reasonable size limitations for a slightly modified tool, the dimensions of the beams were calculated from Equation 2. The beams were subsequently designed from 75S-T6 aluminum alloy, each beam with an effective length approximately 1 inch, width 3/8 inch, and thickness 0.055 inch.

It was found by experiment with the first model of the torque meter (system) that the sliding friction within the tool would be a serious problem in an instrument or system required to measure 0.2 in.-lb. of torque. The design of the modified-handle assembly was then changed to include a ball bearing (Fafnir SK7) between the modified handle and the shaft of the tool. Experimentation with the second model, including the bearing, showed that the frictional torque within the tool was indeed negligible as compared to 0.2 in.-lb.

Figure 1 shows a view of the modified-handle assembly opened, with the moving [redacted] component of the tool in position. Figure 2 25X1
illustrates the moving component of the tool with the modified-handle assembly attached, and the other two parts of the torque meter (system), namely, the circuit box and the meter. (A "Check"-"Run" switch was

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Figure 1. The Modified-Handle Assembly in Position on the Moving Component of the Tool, With the Handle Outer Case Removed

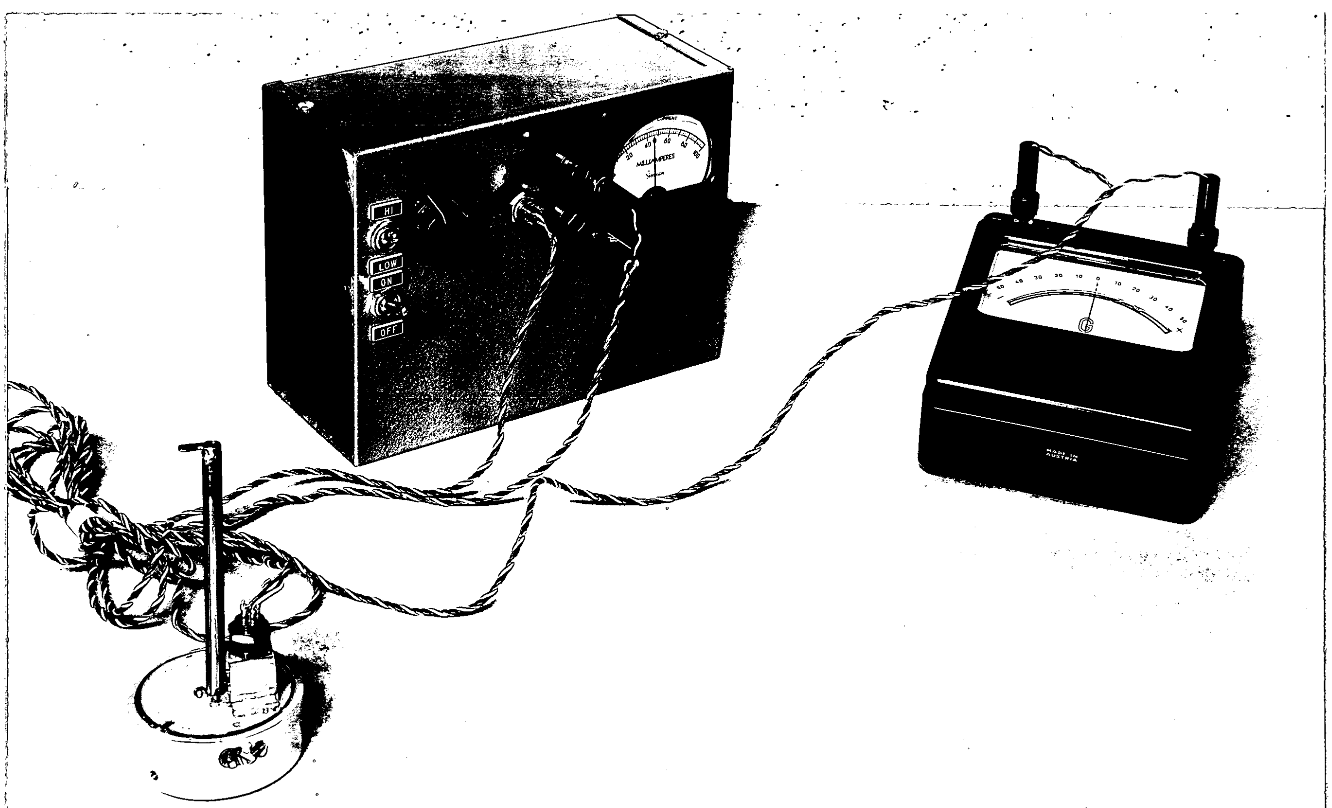

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Figure 2. The Torque Meter (System) Ready for Operation Left to Right: The modified-handle assembly attached to the moving component of the tool; the circuit box; and the indicating meter. (The "Check"-"Run" switch on the circuit box is not shown; it is actually located below the zero-adjustment knob.)

installed on the circuit box, just below the black zero-adjustment knob, after the Figure 2 photograph was taken. This switch was the same type as those used for "On"-"Off" and "Hi"-"Low".) The modified-handle assembly was prepared, for the most part, from an aluminum alloy, and is 2-1/2 inches in OD and 7/8 inch in thickness.

The four strain gages on the two beams (both sides of each) are connected into a closed bridge within the modified-handle assembly. Four lead wires from the four junctions of the bridge are connected to a socket (Amphenol 126-010) on the front cover of the modified-handle assembly (Figure 2). A four-wire cable connects to the tool at this socket, and, at the other end, to the circuit box by means of the same type of socket (Amphenol).

A diagram of the complete electrical circuit is shown in Figure 3.

The two 10,000-ohm resistors and the 1,000-ohm potentiometer at the top of the figure comprise a balancing circuit for zeroing the indicating meter; this is desirable since strain gages of a given type vary in resistance as much as 1% and therefore would not necessarily give a balanced bridge without some adjustment being made. The power source in the working model consisted of two Burgess Type 4156 carbon-zinc batteries connected in parallel, in order to provide enough capacity for 8 hours of operation. At your suggestion, mercury batteries were tried (four Mallory Type TR-134-R), with considerable saving of weight and space, and probably some increase in life.

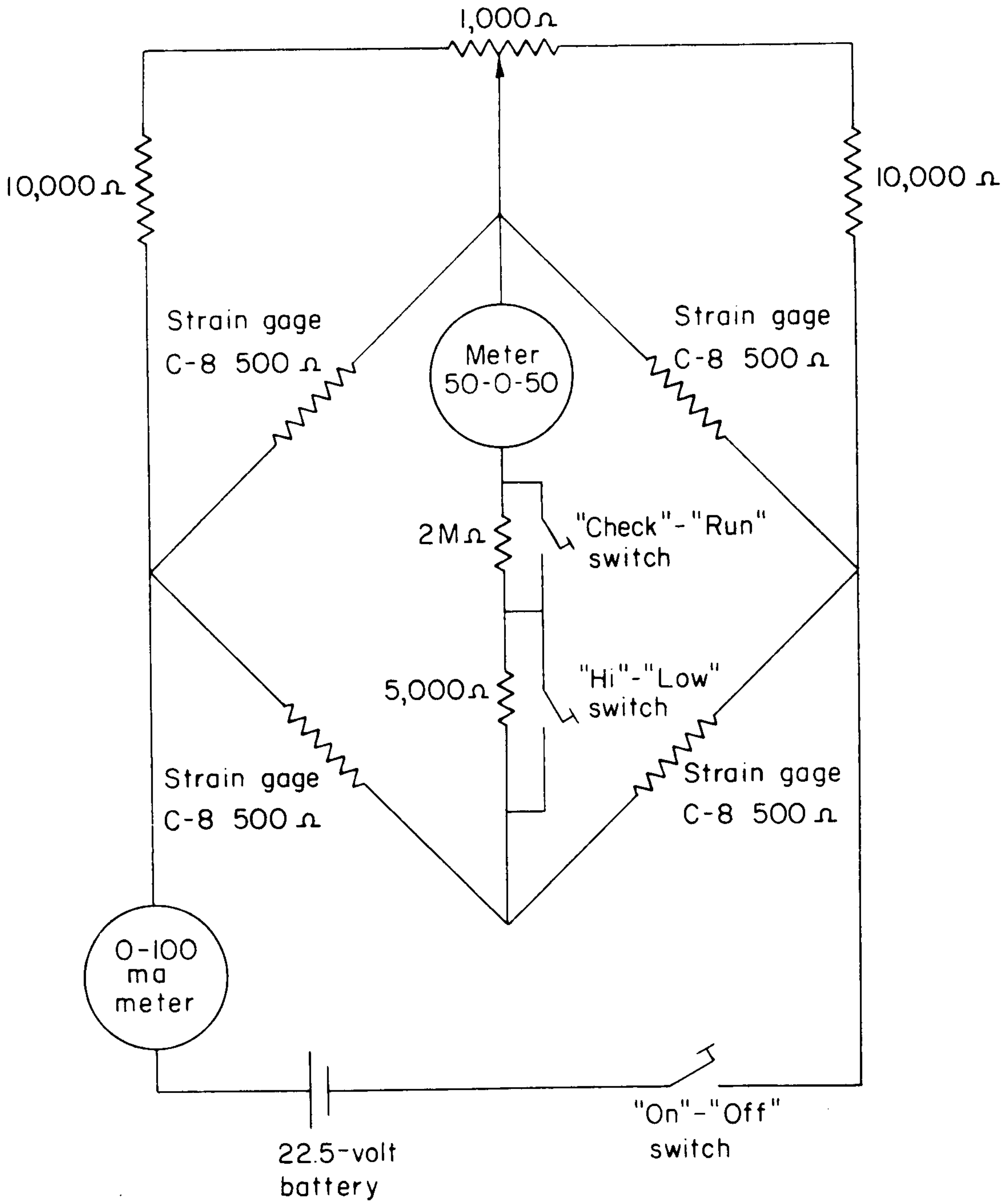

FIGURE 3. CIRCUIT DIAGRAM FOR TORQUE METER (SYSTEM)

The 0-100 ma meter indicates the bridge current and the condition of the batteries. With new batteries (22.5 volts), the current is about 46 ma. The indicated output produced by a torque is proportional to the bridge current. The "Hi"-"Low" switch provides two ranges of sensitivity ("Hi", i.e., high, sensitivity corresponds to the low range of torques, and "Low" sensitivity, to the high range of torques). The indicating meter is a zero-center microammeter with 50 divisions on each side (50-0-50), and with a sensitivity of 0.5 microampere per division and a meter resistance (R_g) of about 300 ohms. It is connected to the circuit box by a two-wire cable with "banana" plugs on each end. The weight of the circuit box and the indicating meter, including the mercury batteries, is about 3-1/4 lb.

In some future model which might be designed for maximum compactness, a circuit box that would be about one half as large as that shown in Figure 2 could probably be prepared, even if a panel-type meter were mounted in the box. A panel-type meter with the required characteristics would be available on special order.

Calibration curves for the two ranges of torque are shown in Figures 4 and 5. It should be noted that a torque of 0.2 in.-lb. (3.2 in.-oz.) produces a deflection of about 8 divisions on the "Hi"-sensitivity scale. Thus, if the need arises, even smaller torques could be measured. With the present circuitry, the maximum readable torque is about 10 in.-lb. It would be desirable in a finalized field model to install appropriate stops so as to prevent the deflection of the indicating-meter pointer beyond full scale in the "Low"-sensitivity range and also

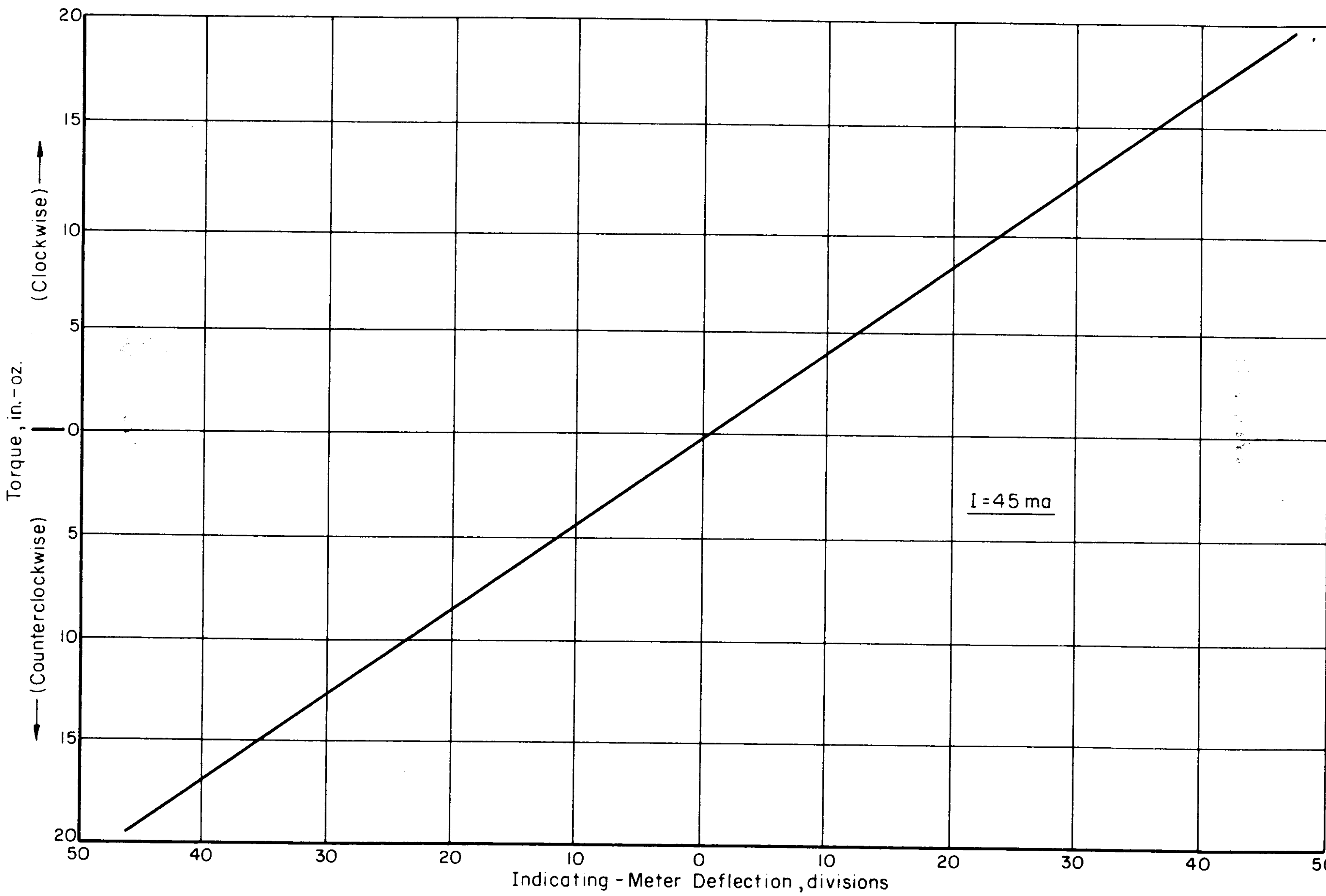

FIGURE 4. CALIBRATION CURVE FOR "HI"-SENSITIVITY RANGE OF TORQUE METER (SYSTEM)

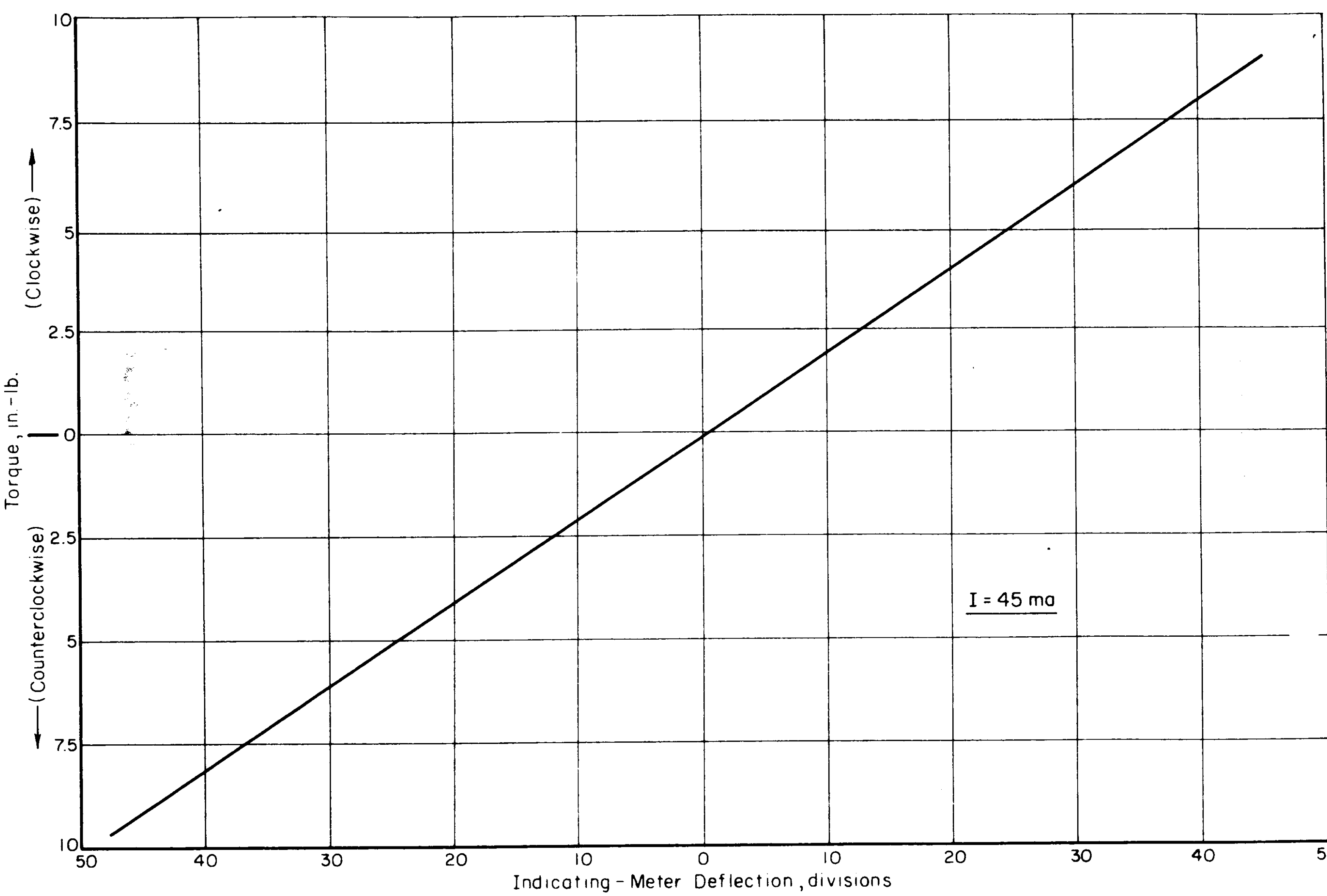

FIGURE 5. CALIBRATION CURVE FOR "LOW"-SENSITIVITY RANGE OF TORQUE METER (SYSTEM)

to prevent overstressing the beams in the modified-handle assembly. As mentioned before, the frictional torque in the system is considerably smaller than 0.2 in.-lb., as evidenced by the return of the indicating-meter pointer very nearly to zero after any deflection even in the "Hi"-sensitivity (low torque) range.

The working model of the torque meter (system) was transmitted to you on September 10, 1959, along with a draft of the operating instructions. The operating instructions are also included here in Appendix 1.

In summary, a working model of a torque meter (system) has been developed which fulfills the objective. The original handle of the special tool has been modified only in size and weight; we believe that the "feel" has been affected very little. Even the working model of the complete instrument (system) is light in weight and relatively small; a refined model could easily be made smaller and more compact. It should be noted also that the indexing device developed previously under Work Order No. III, Task Order No. CC, could be readily fitted to a tool attached to a torque meter (system), if such were desired.

Any consideration of the further development of the torque meter (system) should probably include several refinements of mechanical details in the tool handle, and possibly some refinements in the circuitry to provide checks on its integrity. An improved model of the modified-handle assembly for the tool could probably be prepared so as to be easier to assemble, disassemble, and adjust; also, the size and weight of the assembly might be reduced. Incorporation of the indicating meter as a panel instrument in the circuit box would contribute considerably to compactness and would probably improve the electrical reliability to some extent. It would be possible also to arrange for one meter to do double duty as an indicator of torque and of battery current. Field testing of the torque meter (system) may, of course, suggest other changes worthy of consideration.

Also, a development of possible interest might be the design of an alternating-current (a-c) indicating circuit to replace the direct-current circuitry in the working model. Perhaps the most serious disadvantage of a sensitive d-c bridge circuit is the danger of damage to the indicating meter as a result of an open or short circuit occurring in the strain-gage bridge or in the lead wires to it. It is likely that an a-c bridge would provide several advantages, namely, (1) more sensitivity, (2) a means of protecting the indicating meter against accidental overloads, and (3) a more rugged indicating meter. However, it should be realized that attempting to achieve these advantages might lead to greater weight and size.

Nevertheless, some indication of the improvement possibilities in this direction is furnished by consideration of the Baldwin-Lima-Hamilton Model N transistorized strain-gage indicator. Although this instrument weighs 10 pounds, it could probably be appreciably reduced in weight without any change in performance. The Model N has several features which are not useful for the type of application of interest here; modification of the basic circuitry to provide visual indications without manual balancing could probably be accomplished without an increase in weight. Some measurements were taken with a Model M indicator (the model preceding Model N, with similar circuit and performance), and they indicated that this indicator is several times more sensitive than the circuit incorporated in the working model provided.

We would appreciate any comments that you or your associates might care to make with regard to the research.

Sincerely,

[redacted] 25X1

ABW:mlm

In Triplicate

APPENDIX 1

OPERATING INSTRUCTIONS

Appendix 1

Operating Instructions

The torque meter (system) consists of three major units:

(1) The circuit box, A

(2) The indicating meter, B

(3) The tool and its handle, C.

There are also cables for use in connecting A to B and A to C.

Before connecting the units together with the cables, be sure that the three switches are at the "Off", "Low", and "Check" positions, respectively. Then, proceed as follows:

(1) Turn the "On"-"Off" switch to "On". If the battery-current meter of the circuit box, A, reads about 1 division or less, turn the switch to "Off" and proceed to Step 2. If the reading is appreciably more than 1 division, repairs to the circuit should be made before proceeding.

(2) Use the 4-wire cable with 5-pin plugs on each end to connect the circuit box, A, to the hand tool, C, making sure that the plugs are inserted as far as possible. If the wires of the cable are loose or if the insulation is frayed, repairs should be made before proceeding.

(3) Remove the shunt from the indicating meter, B, and connect this meter, B, to the circuit box, A, with the two-wire cable having "banana" plugs.

(4) Again, turn the "On"-"Off" switch to "On". The battery-current meter should read about 46 divisions (ma) with a new 22.5-volt battery, or its equivalent; used batteries will give a slightly lower reading. Furthermore, it should be possible by turning the zero-adjustment knob to cause the indicating meter, B, to read zero. If the indicating meter, B, can be zeroed, turn the "Check"-"Run" switch to "Run" and re-zero the indicating meter, B, if necessary. The torque meter (system) is now ready for use.

Note: Specific indications of abnormal conditions would be as follows:

(a) A minimum reading which is appreciably different from zero (for example, about 10 divisions or more) on the indicating meter, B, would suggest an open circuit in at least one branch of the strain-gage bridge of the tool handle, C. This would be further substantiated by a battery-current-meter (A) reading in the range 20 to 23 divisions (ma), assuming a battery in fair or good condition. In this case, the circuit must be repaired before the instrument can be used.

(b) A zero or near-zero reading of the indicating meter, B, and a battery-current (A) reading of considerably less than 23 divisions (ma) would suggest that the batteries should be replaced. After a battery is replaced, the above procedure should be followed from the beginning.